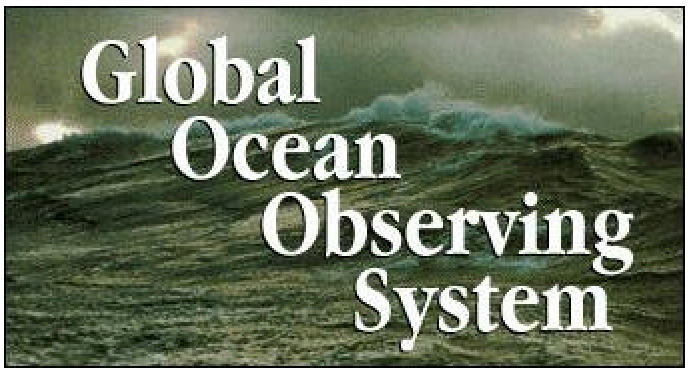
AN OCEAN OBSERVING SYSTEM FOR

U.S. COASTAL WATERS

FIRST STEPS



A U.S. Coastal-Global Ocean Observing System (C-GOOS) Report

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National Oceanic and Atmospheric Administration
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CHALLENGES AND PROMISE OF DESIGNING AND IMPLEMENTING

AN OCEAN OBSERVING SYSTEM FOR U.S. COASTAL WATERS

Workshop, 23-26 May, 1999, Solomons Island, Maryland

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A U.S. Coastal-Global Ocean Observing System (C-GOOS) Report

1 August, 1999

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Executive Summary

The United Nations Conference on Environment and Development calls for the design and implementation of a Global Ocean Observing System to improve climate predictions, document patterns of change in the marine environment and detect and predict the effects of human activities and climate change on marine ecosystems and the living resources they support. In response to a request from Congressmen Curt Weldon and James Saxton, A*Toward a U.S. Plan for an Integrated, Sustained Ocean Observing System*@ was drafted and submitted to Congress in April, 1999. The plan describes the rationale for the observing system and outlines the general requirements for an integrated system that includes both oceanic and coastal components. In regard to the coastal component, the plan makes it clear that (i) many of the elements for an integrated and sustained system are in place; (ii) none of these elements are both integrated and sustained; and (iii) the requirements for the coastal component require a major R&D effort to become fully operational, especially in the realm of biological and chemical sensors.

This report summarizes the results of a workshop (23-26 May, 1999), the goals of which were to (i) begin the design of the coastal component of AToward a U.S. Plan for an Integrated, Sustained Ocean Observing System; (ii) acquaint coastal managers with the potential of *in situ* and remote sensing as a source of data and information upon which to base management policies, plans and decisions; and (iii) acquaint scientists with the needs and perspectives of coastal managers. Recommendations focus on the importance of designing an observing system that builds on existing programs and incorporates the following key elements:

C regional approaches that are locally relevant and nationally coordinated;

C strong constructive feedbacks between monitoring, research and modeling;

C integrated remote and *in situ* sensing capabilities;

C regional centers for data and information management;

C test beds to develop multidisciplinary sensor technologies for *in situ* measurements of biological and chemical properties;

C pilot projects to demonstrate the cost-effectiveness and utility of Aend-to-end, user-driven@ observing systems; and

- index sites to support research and modeling efforts required to develop state-of-the-art operational components and the knowledge required to predict and mitigate the causes and consequences of environmental variability.

Recommendations were made in the context of the emerging design and implementation of the Global Ocean Observing System (GOOS). They represent a consensus of workshop participants as articulated by working groups on (i) detecting and predicting change, (ii) capabilities and needs, and (iii) the design and implementation of an integrated coastal observing system.

Challenges and Promise of Designing and Implementing an Ocean Observing System for U.S. Coastal Waters

I. Background

A. Goals and Rationale of the Global Ocean Observing System (GOOS)

The broad mission of the Global Ocean Observing System is to (i) establish a system that provides the information needed by governments, private enterprise, science and the public to deal with marine-related issues and problems and to (ii) do this through the development of an integrated global network that systematically acquires and disseminates data and data products in a timely fashion. The role of GOOS is to promote the establishment of an observing system that will

C improve weather forecasts and climate predictions;

C document patterns of change in the marine environment; and

C detect and predict the effects of human activities and climate change on marine ecosystems and the living resources they support.

If these goals are to be achieved, observations must be sustained and integrated. Observations must be sustained in perpetuity to both capture episodic events and long-term trends and support model predictions.[1] The observing system must also be integrated in terms of (i) the diversity of measurements made from common platforms; (ii) the integration of measurements made on different time and space scales; and (iii) the wide range of user groups that utilize GOOS products. To date, no single program is both integrated and sustained. For example, numerical weather predictions and *in situ* measurements of sea level are sustained but are very narrow in scope. IGBP programs such as LOICZ, JGOFS, and GLOBEC are integrated in the sense that they are multi-disciplinary in scope, but they are not sustained. The Global Ocean Data Assimilation Experiment (GODAE) is an emerging effort to be both sustained and integrated.

In addition to being sustained and integrated, the observing system must be responsive to user needs and operational. The measurement program must be sustained to capture the temporal and spatial dimensions of environmental patterns; measurements must be routine with known precision and accuracy; data must be transformed into products in a timely fashion; and the entire process from measurement to product must be cost-effective with minimal lags between measurements and the generation of products. Thus, GOOS is conceived as an Aend-to-end, user-driven@ system, the operational objectives of which are to

$ develop a locally relevant, global scale observing system for multiple uses that is sustained, integrated, operational, comprehensive and cost-effective;

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[1]Note: The term Aprediction@ is used here in its broadest sense to include forecasting or predicting future events as well as estimating (interpolating, extrapolating) a quantity which is not observed directly.

$ specify the measurement programs and information required on a continuing basis to meet user group needs on local to global scales;

$ design and promote the implementation of an internationally coordinated strategy for the timely acquisition, dissemination, analysis and archival of data;

$ incorporate existing programs as appropriate to minimize redundancy and optimize shared use capabilities;

$ enable all nations to participate and benefit from GOOS; and

$ coordinate with GCOS, GTOS and other observing systems to insure the full integration of environmental data and information.

International agreements that enable and call for the establishment of a GOOS include (i) the 1982 UN Convention on the Law of the Sea and (ii) three conventions signed at the 1992 UN Conference on Environment and Development (UNCED) in Rio de Janeiro: the Framework Convention on Climate Change, Convention on Biodiversity and Program of Action for Sustainable Development, Agenda 21. The Law of the Sea Convention provides the legal basis for implementing GOOS by defining jurisdictions in the form of territorial seas and the EEZ. Agenda 21 calls for the establishment of a global ocean observing system that will enable effective and sustainable management and utilization of the marine environment and its natural resources and develop the capacity to predict future changes with known certainty. GOOS was created in 1992 as part of an Integrated Global Observing Strategy that includes the GCOS (Global Climate Observing System) and GTOS (Global Terrestrial Observing System). GOOS is the ocean component of the GCOS and the coastal marine component of the GTOS. It is sponsored by the Intergovernmental Oceanographic Commission (IOC), the United Nations Environmental Program (UNEP), the World Meteorological Organization (WMO), and the International Council of Scientific Unions (ICSU).

B. Coastal GOOS

As indicated by the broad spectrum of changes occurring in coastal ecosystems (Table 1), human activities are having a profound impact on coastal ecosystems and on the susceptibility of coastal populations to natural hazards. Mitigating these effects and managing impacts depend on improved coastal ocean observations and more timely dissemination of products derived from them. **The scarcity of observations on coastal ecosystems of sufficient duration, spatial extent, and resolution and the lack of real-time data telemetry, assimilation and analysis are major impediments to the documentation of pattern and to the development of a predictive understanding of environmental variability and change in coastal waters**.

Table 1. Prominent natural perturbations and anthropogenic stresses and associated indicators of change in coastal aquatic ecosystems.

PERTURBATION - STRESS

- Natural hazards and variations in annual weather cycles (wind, precipitation, temperature, storm surge, freshwater runoff and ground water discharge)
- Climate change (temperature, sea level, salt intrusion, regional weather patterns)
- Physical restructuring of the environment (e.g., land-use practices, alteration of fresh water flow patterns, dredging, shipping)
- Nutrient mobilization and enrichment of coastal waters
- Chemical contamination of air, soil and water
- Exploitation of living resources
- Introductions of nonindigenous (exotic) species

INDICATORS OF CHANGE

- Decline and loss of living resources
- Habitat loss, erosion and oxygen depletion
- Excessive accumulations of algal biomass and harmful algal blooms
- More fish kills and mass mortalities of birds and mammals
- Diseases and accumulations of chemical contaminants in marine organisms
- Growth of nonindigenous species
- Loss of biodiversity
- Temperature increase, sea level rise and salt intrusion (rivers, ground water)
- Increase susceptibility to natural hazards, public health risk

Although the list of indicators of environmental change in coastal waters is long, they are related in terms of ecosystem dynamics suggesting that there is a common set of core properties that, if measured with sufficient resolution in time and space, can be used to detect long-term environmental trends, forecast environmental changes, and predict the consequences of human activities and climate on coastal ecosystems and the quality of life. Thus, the role of C-GOOS is to promote

$ the use of remote and *in situ* sensing technologies and real-time data acquisition and analysis;

$ more timely exchanges of information among terrestrial and estuarine ecologists, oceanographers and meteorologist to achieve interdisciplinary, problem-driven approaches that transcend traditional boundaries of land, sea, and air;

$ the establishment of more effective linkages between environmental science and society to produce products that meet the needs of user groups both within and outside the scientific community; and

$ the implementation of measures to increase public and political awareness of environmental issues in the coastal zone for the formulation and implementation of ecologically and economically sound environmental policies.

Additional information on the coastal component of the Global Ocean Observing System is given in Appendix A.

C. Toward a U.S. Plan for an Integrated, Sustained Ocean Observing System

In August 1998, Congressmen Curt Weldon (R-PA) and James Saxton (R-NJ) requested John Dalton, the Secretary of the Navy, and D. James Baker, Undersecretary of Commerce for Oceans and Atmosphere (Chair and Vice Chair, respectively, of the National Ocean Research Leadership Council B NORLC) to "propose a plan to achieve a truly integrated ocean observing system." Dr. Baker agreed to take the lead in forming a team to draft an initial plan for developing an integrated, sustained ocean observing system would be submitted to Congress in early 1999. The task team was chaired by Worth Nowlin (Texas A&M University, Chair of the Steering Committee for the international Global Ocean Observing System) and co-chaired by Thomas Malone (University of Maryland Center for Environmental Science, Chair of the International Coastal GOOS Panel). The team consisted of both federal and non-federal scientists who have familiarity with related efforts already underway. Advice was obtained from the U.S. GOOS Steering Committee, co-chaired by Nowlin and Malone. The resulting report, A*Toward a U.S. Plan for an Integrated, Sustained Ocean Observing System*@, was reviewed by the NORLC=s Ocean Research Advisory Panel (ORAP) to the National Oceanographic Partnership Program (NOPP), and transmitted to Congress on 20 April, 1999. A synopsis of the coastal component of AToward a U.S. Plan for an Integrated, Sustained Ocean Observing

System@ is given in Appendix A. The full plan has been posted on the NOPP website:

<http://core.cast.msstate.edu/NOPPobsplan.html>

A subcommittee of the ORAP has been established to elaborate on this document and submit an updated plan to Congress in 2000. This plan will be based, in part, on workshop results summarized below.

II. Designing and Implementing an Ocean Observing System for U.S. Coastal Waters

A. Workshop Goals

The workshop brought together representatives from government (state and federal) and academia who have direct, hands on experience with and responsibility for *in situ* sensing (platforms or sensors), remote sensing, real time telemetry, systems modeling, data assimilation, and the stewardship of coastal environments and living resources (Appendix B). The goal was to evaluate requirements for and the ingredients of an integrated coastal ocean observing system. Participants were asked to address three related issues:

C detecting and predicting change in coastal ecosystems;

C monitoring capabilities and information needs; and

C the design and implementation of an integrated, multidisciplinary coastal observing system.

Objectives were to (i) initiate the next iteration of A*Toward a U.S. Plan For an Integrated, Sustained Ocean Observing System*@ with particular reference to coastal issues; (ii) acquaint state managers with the potential of *in situ* and remote sensing as a source of information upon which to base management policies, plans, and decisions; and (iii) acquaint scientist with the needs and perspectives of coastal managers responsible for the stewardship of coastal environments and the living resources they support.

B. Organization

The workshop began on Sunday, 23 May with a keynote address by Dr. Nancy Foster, Assistant Administrator of the National Ocean Service of NOAA. This was followed by three full days (Monday-Wednesday) of plenary and breakout group sessions as described below. Margaret Davidson, Director of the Coastal Services Center, addressed the group on Tuesday evening to emphasize the importance of responding to the challenge. Each day began with plenary talks by invited speakers, the purposes of which were to set the stage and stimulate discussion. These were followed by working sessions to determine needs, priorities and goals for coastal observing systems. Plenary talks were based on background papers prepared for the workshop. Abstracts of the following papers are given in Appendix C:

$ Glenn, S.M., W. Boicourt, T.D. Dickey and B. Parker. Long-Term, Real-Time

Observation Networks for Ports,

- $ Haidvogel, D.B., J. Blanton, J.C. Kindle, and D.R. Lynch. Coastal GOOS: Processes, Models and Real-Time Systems

- $ Walstad, L.J. and D.J. McGillicuddy. Data Assimilation for Coastal Observing Systems

- $ Weisberg, S.B., T.L. Hayward, and M. Cole. Towards a U.S. GOOS: A Synthesis of Lessons Learned form Previous Coastal Monitoring Efforts.

- C Fox-Norse, V., R. Bailey, W. Boynton, A. Frankic and J. Proni. Driving Science and Management Issues and Related Information Needs for Developing and Implementing Environmental Policies in the Coastal Zone

1. Day 1 (24 May): Detecting and Predicting Change

The focus of this phase of the workshop was on the need for Aend-to-end@ observing systems that employ *in situ* and remote sensing, real-time telemetry, and assimilation modeling for the purposes of environmental and resource management and forecasting the occurrence and impacts of coastal hazards (Appendix D). The session began with plenary talks by Dale Haidvogel, Leonard Walstad and Scott Glenn. Following the talks, participants were divided into four working groups, each charged with designing an integrated observing system that meets the needs of multiple users and is operational for Estuaries and the Open Shelf. Ageneric@ coastal ecosystems subject to different external forcings (stresses):

- $ ports (shipping),

- $ watershed/estuary (nutrient enrichment),

- $ wide shelf (fishing), and

- $ narrow shelf (climate change).

The selection of these combinations was not intended to suggest that a particular forcing is unique to a particular ecosystem or that all coastal ecosystems fall into one of these four categories. They were selected as examples because they involve a broad spectrum of issues that must be considered if an integrated, ecosystem level approach to coastal monitoring is to become a reality.

Each working group was multi-disciplinary in that they included representatives of each link in an end-to-end design from the users of environmental data products to the scientists and technicians make the measurements and analyze the resulting data. The operational goal was to inform scientists of user needs and acquaint users (emphasis on representatives from state agencies responsible for environment and living natural resources) with the potential of systems that incorporate *in situ* and remote sensing, real time telemetry, and assimilation models to meet their information needs. Working groups were asked to follow the C-GOOS design procedure given in Appendix A.

2. Day 2 (25 May): Comparative Analysis of Capabilities And Needs

Day 2 focused on different links in an end-to-end observing system. The day began with plenary talks by Steve Weisberg and Virginia Fox-Norse. Following the talks, participants were divided into four working groups (Appendix E): (i) end users (e.g., individuals responsible for the management of living resources and water quality) to discuss regional differences and similarities in priority issues that would benefit most from an integrated observing system; (ii) observational oceanographers to discuss research and development needs for *in situ* sensors; (iii) observational oceanographers to discuss current capabilities and research and development needs for remote sensing; and (iv) modelers to discuss research and development needs for prediction. It was recognized that data management (collection, transmission, distribution, QAQC, and archival) is a major problem that must be addressed, but an in depth treatment is beyond the scope of this workshop. This should be coordinated with and build on the coastal data management initiative of NODC and NAML.

3. Day 3 (26 May): Design and Implementation of an Integrated Coastal Observing System

Based on the results of the first two days of work, the final full day focused on the development of guidelines and recommendations for the next iteration of AToward a U.S. Plan for an Integrated, Sustained Ocean Observing System.@ Four groups were tasked to review the coastal component of the plan with the goal of formulating recommendations to take the coastal component to the next step. The four groups were chaired by John Cullen, Tommy Dickey, Dale Pillsbury, and Gary Powell. Their reports were similar and are presented in integrated form below.

III. Workshop Conclusions and Recommendations

A. A Framework for Coastal GOOS

The coastal component of *AToward a U.S. Plan for an Integrated, Sustained Ocean Observing System@* was generally considered to be a reasonable starting point for the design and implementation of an integrated observing system for coastal ecosystems. Environmental problems of immediate concern include improved predictions of natural hazards and seasonal and interannual changes in regional weather patterns and their economic and ecological effects; physical restructuring of the environment; nutrient mobilization and enrichment of coastal waters; chemical contamination of air, soil and water; exploitation of living resources; and introductions of nonindigenous (exotic) species. Climate change and its consequences are, of course, the principal long-range concerns that must be addressed by the observing system. In these regards, the next iteration of the U.S. plan should include better definition of objectives and products; effective interagency collaboration from design to implementation; identification of pilot projects and research and development priorities for multidisciplinary sensor systems; and the development of a regional approach to full scale implementation.

1. Clearly Define Objectives and Products

The importance of clearly defining objectives and anticipated products was emphasized by all four working groups. The tendency with new, large programs is to define broad, overarching goals in an attempt to achieve consensus and establish a broad funding base. While these are necessary first steps, specific objectives that can be realistically achieved and are locally and regionally relevant must be articulated at the onset.

In addition, the most successful programs have been those with clearly defined uses and users for the data they produce. Achieving this requires that data providers (scientists) and Aend users@ interact to design, implement, and evaluate the observing system. This broadens the horizons of decision makers and other users by familiarizing them with the array of possible measurement, dissemination, and analytical systems while at the same time providing the technical experts with an understanding of the data and information needs of user groups.

It is also clear that the objectives and products will change with increasing knowledge and technical capabilities and that hypothesis-driven, mechanistic research studies are of limited value unless they are done in the context of sustained, long-term observations. Thus, **the design of an integrated observing system must incorporate an interactive program of research, modeling and observation to insure accurate documentation of patterns of variability, quantitative understanding of causes and effects, and predictions of known certainty**.

2. Coordination and Collaboration

Although research and monitoring have improved our understanding of coastal ecosystems, and management actions to mitigate the effects of human activities have achieved some successes, important challenges remain and new challenges have emerged in recent years. Meeting these challenges will require fundamental changes in the traditional approaches used in the environmental sciences and in the management of living resources and the environmental impacts of human activities. An unprecedented level of coordination and collaboration among government agencies and the scientific community will be required to design and implement the regional and comparative ecosystem approaches needed not only to enable more effective monitoring, analysis and prediction of environmental change in local ecosystems, but also to achieve

An overriding operational objective of C-GOOS must be to promote synergy among local and regional programs for the establishment of a locally relevant, nationally coordinated and credible observing system. Critical information from local-regional, issue-driven programs should be integrated into a national framework. The goal is to provide, with due consideration of larger scale (e.g., global) influences, the context required to assess and predict local changes in U.S. coastal waters. This can only be achieved through the development of an integrated, comprehensive, and readily accessible description of ocean circulation and the distributions of physically and ecologically relevant properties.

The need for a sustained, multi-disciplinary observing system has been recognized for sometime. Much of the difficulty in designing and implementing sustained research and monitoring programs in coastal ecosystems is related to the failure to develop regional and national consensus on information needs and to the failure to develop the management infrastructure required to support the research and monitoring programs that provide the data and analysis that satisfy these information needs. An important factor contributing to the lack of infrastructure support is the fragmentation of stakeholders in maritime transportation, recreational use of waterways, commercial and recreational fisheries, land-use planners, water resource boards,

Biological and physical processes in nature exhibit characteristic scales of variability that are related in a multi-

economies of scale.

stewardship of the environment, etc. At least 8 federal agencies (Commerce, Navy, Interior, Transportation, Energy, NSF, EPA, and NASA) have responsibilities for collecting ocean data and supporting environmental research. Agency budget requests and programs are reviewed and approved by 47 different Congressional Committees and Subcommittees. Such fragmentation makes the challenge of designing and implementing the coastal component of the U.S. ocean observing system a formidable one indeed.

3. Toward an Operational System

Many of the observations required to address issues in coastal ecosystems (e.g., Table 1) are not operational and much work is needed to determine those products that will be most useful. In this context, pilot projects, index sites, and test beds are needed to serve at least one of the following purposes: (i) demonstrate the usefulness of the end-to-end approach (proof of concept); (ii) advance understanding of coastal ecosystems and power to predict patterns and change in them with know certainty; and (iii) incorporate research and development programs needed for an integrated, multidisciplinary observing system that incorporates synoptic measurements of biological and chemical variables as well as physical and meteorological variables.

4. Regional Approaches

dimensional continuum of time, space and ecological complexity. Large spatial scales tend to be associated with long time scales and with greater ecological complexity, and small scales tend to be associated with short time scales and with less ecological complexity. Small and large scales of variability are linked on regional scales via hierarchies of physical and biological interaction. In this context, the purpose of regional research and monitoring is to understand how energy and matter are propagated to larger or smaller scales of organization, e.g., how events and processes at higher levels of organization and larger scales influence local systems of concern. Here, **Aregional marine research@ is used in a relative sense and to emphasize its importance in bridging the gap between locally, highly resolved research** (e.g., COP, LMER, LTER, CoOP, LOICZ, JGOFS, GLOBEC) and larger scale observations (e.g. CEOS, GOOS, GCOS, GTOS).

A regional perspective linking changes in global climate and land-use practices in coastal watersheds to changes occurring in coastal waters is needed to document, predict, and mitigate the effects of natural perturbations and anthropogenic stresses on coastal ecosystems. A regional approach is not only important for understanding the dynamics of coastal ecosystems and predicting the socioeconomic consequences of change, it also provides a tractable means of addressing a variety of operational problems related to data management, linking the users of environmental information with data providers, and the fragmented nature of the nation=s environmental programs. Thus, it was generally agreed that the observing system should be designed and implemented region by region and that regional data management-synthesis centers are a key ingredient in the linkage of end users to measurement programs. It was noted that the planning process employed by the **Regional Marine Research Program** in the early 1990's provides a basis for initiating the design of a nationally coordinated program of regional observing systems (Public Law 101-593; the so-called AMitchell Bill@).

Implementation will require the establishment of a national management structure based on regional building blocks. This will require **leadership** (advocacy and vision to represent the program regionally and nationally), **coordination** (setting priorities to emphasize regional strengths and represent regional problems and characteristics; coordinate and integrate activities of components leading to consensus opinions for coastal US), **responsible oversight** (establish needs and standards, oversee observing system structure; assure that evaluation of observing system occurs), **assessment and adaptability** (evaluate progress and adapt to new needs and capabilities), and **outreach** (work with agencies and other users toward improvement of methods for using observations of the ocean to make decisions and to engage the public at large).

B. Key Elements

Key elements for implementation are data and information management, systematic evaluation of regional needs, and the establishment of prototype networks using established sites, projects and programs.

Data management is of central importance and, for the most part, is currently done on a project-by-project basis. Data management must also enable a constructive and timely interaction between monitoring programs and hypothesis-driven research. A more integrated approach should be implemented that addresses the needs of user groups as well as the development of common protocols, intercalibration procedures, quality control, timely data dissemination, and archival.

A coastal data information system should be established that utilizes and enhances existing national and regional data center capabilities to serve the coastal component of U.S. GOOS. This system must be flexible to accommodate disparate data types and scales of sampling, including emerging and new technologies; and it must be accessible with data that are suitable for a broad audience, including multi-user capabilities and real time data dissemination. Initial efforts should focus on regional approaches to data management and synthesis that can be networked to achieve national scale assessments.

The National Oceanographic Data Center (NODC) has begun to work with external data centers and is active in planning for the regional development of U.S. Coastal GOOS. This effort should be coordinated with a parallel project of the National Association of Marine Laboratories (NAML). NAML is in the process of designing and testing ALabNet@ as a means

1. Data and information management

of networking laboratories for more timely access to data and information and cost-effective monitoring of coastal waters. The goal is to provide the infrastructure required to exchange and integrate data collected at different locations, on different time and space scales, using different methodologies for a nearly seamless analysis and visualization of patterns.

2. Evaluate needs

Assess the extent to which existing programs are providing the data needed to achieve the goals of a nationally integrated ocean observing system. Critical steps include the following:

C Ensure the development of hypothesis-driven, mechanistic research projects and related systems modeling in the context sustained, long-term observations.

$ Evaluate the spatial and temporal scales of measurements required to quantify external inputs (e.g., fresh-water, nutrients, atmospheric deposition, and offshore transport) to coastal ecosystems and enhance current monitoring programs accordingly.

$ Address the problem of Aunder-sampling@ in coastal waters by building the Abackbone@ for a monitoring and data assimilation system through systematic analysis of sampling needs (e.g., fill sampling gaps with specific measurements through the application of observing system simulation experiments (OSSEs) and careful cost-benefit analysis).

$ Identify key physical, biological and chemical variables that should be measured synoptically in time and

3. Initiating the coastal ocean observing system: a nesting of networks

a. National elements

The beginnings of a framework for an integrated ocean observing system are emerging in the form of satellite remote sensing (NASA, Ocean Biology and Biogeochemistry; NOAA, CoastWatch) and *in situ* measurement programs (e.g., NAWQA, PORTS, NOS tide gauge network, the COE network of wave gaging stations, and the NDBC network of meteorological buoys including C-MAN sites).

$ NASA and NOAA Satellite systems have the potential of providing spatially synoptic data on coastal erosion and sediment transport, surface waves and currents, sea level, frontal systems, river plumes and phytoplankton productivity (see working group report on remote sensing).

$ CoastWatch delivers high resolution, near real-time environmental satellite data and data products to federal, state, local and tribal resource managers, marine scientists and educators.

$ The National Water-Quality Assessment Program (NAWQA) of the U.S.G.S. is designed to assess the status and trends in the quality of the nation=s ground- and surface-water

space; enhance R&D efforts to produce the required sensor technologies; and build these technologies into this backbone based on regional needs and priorities.

resources. The coastal component of this program is critical to the estimation of material (water, sediment, nutrients, contaminants) inputs to coastal waters.

$ Data on water level is currently monitored by NOAA-NOS at approximately 200 locations. NOS has also established PORTS (Physical Oceanographic Real-Time) Systems in 5 major U.S. ports. PORTS provides real-time data on currents, water levels, water and air temperature, winds and barometric pressure required for safe and efficient marine operations.

$ The Corps of Engineers (COE) operates a network of ~50 wave, current and water level monitoring stations in U.S. coastal waters (5-20 m depth) and harbors as part of their field wave gaging program.

$ The National Data Buoy Center (NDBC) operates a network of environmental monitoring platforms in coastal and oceanic waters that provide meteorological data to the NWS (and others) for weather forecasting and coastal hazard alerts. The network consists of ~62 moored buoys and 52 fixed platforms (Coastal Marine Automated Network or C-MAN). The stations are automated and report meteorological and oceanographic data via Geostationary Operational Environmental Satellites

(GOES). An important feature of this network is that the data acquisition and processing electronics for *in situ* sensing are in place, and the system can easily be enhanced to include additional physical, biological and chemical sensors.

These programs should be enhanced to address the critical problems (i) of under-sampling in space (greater resolution over larger areas) and time (greater resolution over long periods) and (ii) of providing the core data that will be required by several end users regardless of location or region (e.g., water depth, shoreline geometry, meteorological variables, and 3-D fields of temperature, salinity, currents, nutrients and chlorophyll).

b. Pilot projects

Within this national framework, a set of established regional sites or programs should be identified to serve as an initial demonstration of coastal observing and prediction system capabilities. This would include integration of the data from these programs to develop information products as demonstrations to users, e.g., nowcasts of current conditions (sea state, near shore water temperatures along coastal beaches, bottom water hypoxia, harmful algal blooms, etc.), improving the timeliness of data analysis to document environmental trends (hindcasts), and providing prototype predictions to test hypotheses, improve measurement programs and modeling, and, where appropriate, make operational forecasts (e.g., natural hazards, water level, sea state, effects of land-use practices, harmful algal blooms, etc.).

The list of potential pilot projects is long, e.g., the Gulf of Maine Observing System, the Chesapeake Bay Observing System, Georgia Towers, Tampa Bay PORTS-West Florida Coastal Ocean Monitoring and Prediction System, CalCOFI, Santa Barbara Channel-Santa Maria Basin Circulation Study, SIO Marine Observatory, Texas Automated Buoy System, the Great Lakes Forecasting System, National Estuary Program, National Marine Sanctuary Program, and NERRS Monitoring Program. The National Oceanographic Partnership Program (NOPP) has also funded several projects that involve the development of regional observing systems, sensors and sensing elements, and modeling and data assimilation.

None of these projects are both sustained and integrated (multidisciplinary with both *in situ* and remote measurements). All are potential pilot projects for the design and implementation of U.S. GOOS. A selection process should be developed to identify those that, when regionally networked, are likely to provide information and services that could not be provided by other means or would enable more cost-effective and timely dissemination of data and information.

c. Index sites

Index sites and test beds should be developed to (1) improve and enhance observing system technologies and models to link measurements to products in the form of predictions and early warnings, to (2) demonstrate the efficacy of the GOOS approach, to (3) facilitate the transformation from research to operational modes, and to (4) define baseline conditions for quantitative assessments of variability. This step in the implementation includes introducing the next generation of observing system capabilities, directed at a problem and its solution, i.e., issue-oriented.

Intensive measurements and modeling of physical, biological, and chemical processes at selected sites (index sites) will be needed to quantify causal relationships and to develop technologies and models required to enhance the ability of the observing system to detect and predict change in real time. Index sites provide the link between large scale survey and monitoring programs and the basic research required to understand causal relationships and predict change in coastal waters with known certainty. In this regard, index sites may also serve as test beds to develop and test new methods and technologies that may be incorporated into the observing system. Examples of potential index sites for regional and national networks include the Coastal Intensive Site Network (CISNet), coastal Long-Term Ecological Research (LTER), and Long-term Ecosystem Observatories (LEO).

C. First Steps

1. Improve the description of the physical environment including the lower atmosphere, the pelagic environment and the benthos:

$ establish an *in situ* sensor network;

$ improve modeling and assimilation technologies;

$ develop more accurate and robust algorithms for translating remote measurements of ocean color into concentrations and plant pigments and other biologically reactive constituents; and

$ insure sustained observation from space.

2. Improve estimates of inputs of freshwater, sediments, nutrients and chemical contaminants:

C increase the number of gauging stations;

C add appropriate measures of sediment load and chemical constituents.

3. Establish a hierarchical observing systems from local index sites to regional networks of index sites and observing systems (e.g., ports-estuary-open shelf-open ocean) and a national network of regions:

$ link federal programs with local-regional partnerships to insure that programs are relevant;

$ establish reference sites that provide for comparative analysis on regional to national scales and for the assessment of status and long-term trends.

4. Establish a national data and information management system consisting of regional synthesis centers:

- provide regional resources for the storage and retrieval of environmental data and information;

- insure national coordination of data for the purposes assessing larger scale
- promote links to national and international remote and *in situ* sensing programs.

5. Promote, coordinate and communicate locally relevant observations collected by regional partners:

changes and commonalities (e.g., the ubiquitous nature of local changes, temporal coherence of changes);

- establish regional teams of stakeholders to establish priorities and coordinate the development of regional observing systems;

- promote technology transfer and demonstration sites.

Appendix A

The Coast Component of the Global Ocean Observing System

I. A Synopsis of International C-GOOS

A. Overall Design

The ultimate goal of C-GOOS is to provide the basis, in observations and models, for assessing the effects of human activities and for predicting change in coastal waters. The design strategy being developed for C-GOOS is based on the parallel development of global and regional scale components:

$ a global network to document the global dimensions of local to regional patterns of change in coastal waters and to provide the large scale perspective required to distinguish between locally generated patterns and those generated by regional-global scale forcings; and

$ regional networks that incorporate selected index sites where high intensity observations provide the basis for understanding the causes and effects of environmental variability and for the development of models required for analysis and to translate data into useful visualizations and predictions.

The first step is to formulate a procedure for designing an Aend-to-end@ observing system that links measurement programs to user needs. Critical links between these Aend members@ include identification of user groups; precise definition of the attributes to be predicted or described; determination of acceptable time lags between observation, model outputs, and the delivery of products; determination of acceptable levels of accuracy and precision; identification of models that are to be used to link measurements to products; and the definition of model inputs and outputs. The procedure may be summarized as follows:

1. User groups

Identify the users of C-GOOS information and products and define their needs.

2. Final Prediction

Define the final form(s) of the prediction. It is recognized, for example, that coastal managers do not need predictions about the possible occurrence of a red tide in the form of a complex model output. A straight forward alert may suffice. On the other hand, a coastal engineer designing flood defenses may need a precise confidence interval for the probability that a critical level will be exceeded or the captain of a container ship may need precise predictions of water depth in the Port of New York. **The term prediction is not used simply in the sense of forecasting the future, but also in the sense of estimating (interpolating, extrapolating) a quantity which is not observed directly**, e.g., inferring the present biodiversity of an ecosystem from measurements made at a small number of stations, estimating return times of extreme sea-levels at a coastal site with no sea-level data from a tide gauge with a long record at another site.

3. Lead Time

Lead time is the acceptable time lag between measurement and prediction. For cases involving straightforward spatial interpretation this may be zero (e.g., the probability of a specified sea-level being exceeded at a site without a tide gauge). On the other hand, useful storm surge forecasts are required hours to days ahead while land use management decisions might be based on GIS products that require days-months to produce.

4. Identification of the Types of Models to be used

Models will range from conceptual models, GIS, and simple regression models (based on empirical relationships) to sophisticated, coupled ocean-atmosphere and hydrodynamic-ecosystem models based on theory and empirically derived parameters.

5. Model Outputs

This describes the quantity predicted directly by the model. It might be, for example, time-varying fields of currents or productivity, linear trends of sea level over recent decades, or ice distribution. In many instances this will differ from the final form of the prediction provided to users which will commonly be a highly reduced version of the raw model output.

6. Model Inputs

These are the measured variables required by models to make predictions, e.g., winds, air pressure, sea-level, currents, sea surface temperature and salinity, concentrations of nutrients, chl-a, O_2.

7. ACost-benefit@ analysis

The feasibility of each measurement and its impact are ranked high, medium or low. Feasibility is assessed in terms of cost, difficulty of measurement, and/or the availability of acceptable technologies and techniques. Impact is assessed in terms of the importance of the measurement to decision making or the effect on model output if an input variable is not measured, is measured infrequently, has a large error associated with the estimate, is aggregated with other variables, etc. In an impact-feasibility matrix, properties may fall, for example, into the following categories: (i) the property is easily measured (routine) and has a high impact; (ii) the property has a low impact and is difficult to measure (not routine or the technology does not exist); and (iii) the property has a high impact and is difficult to measure. Properties that fall into category (iii) should be the subject of active R&D to move them to category (i).

It should be emphasized that this is an iterative process. For example, the type of model(s) used will be determined by a combination of factors including (i) desired final predictions, (ii) required lead time(s), (iii) available model inputs, and (iv) cost-benefit analysis.

The achievement of the goals of C-GOOS will depend to a great extent on a synergy between C-GOOS and research programs such as LOICZ, LMER, CoOP, GEOHAB, JGOFS, and GLOBEC. C-GOOS will promote the use of the new knowledge and technology advances generated by research programs for applied purposes and provide the framework of observations required to understand the global significance of results from research on targeted ecosystems. At the same time, the knowledge and tools generated by these programs will benefit the observing system through better quantitative understanding the causes and consequences of environmental change; more effective technologies for real time monitoring and data telemetry; improved analysis and visualization of changes in real-time; and the development of models for improved prediction, nowcasting and forecasting environmental change.

B. An Operational Ocean Observing System

An operational observing system requires that measurements are routine, long-term (sustained into the foreseeable future), and systematic (made with sufficient precision and accuracy on time and space scales appropriate for the issues being addressed). An integrated observing system that is relevant to the needs of society should have the following characteristics:

- Addresses issues that fall within one or more of the categories listed in Table 1;
- Involves observations that extend beyond national (or state) boundaries and require multi-national (or -state) coordination and collaboration;
- Integrates observations from different sources collected for different purposes and is responsive to the requirements of multiple users;
- Coordinates and links measurement and data management programs among nations (states) to minimize duplication, reduce costs, and maximize data availability;

- $ Integrates remote aircraft, satellites, land-based high frequency radar) and *in situ* measurements (moored instruments, drifters, AUVs, ships) to capture spatial and temporal dimensions of change in both surface properties and with depth;
- $ Develops an integrated information management plan that ensures continuous data-streams, timely delivery of data and information, and adequate quality control;

- $ Measurement programs, data management and product delivery are subjected to periodic evaluation in terms of their cost-effectiveness and utility; and

- $ Adapts to new and changing user requirements for ocean data and products.

C. Data Management

Historically research and monitoring programs have been developed independently of one another, case-by-case by different nations, agencies and institutions to address specific issues and mission based goals. The result are programs that

- $ employ different platforms and methods;

- $ make measurements on different time and space scales; and

- $ use different data management systems

- $ designed primarily for the purposes of a particular nation, government agency or institution.

As the international and multidisciplinary nature of most coastal environmental issues have become clear, efforts to collate and integrate data from a variety of sources have increased. Under present conditions, this is an expensive, time consuming process that forces retrospective analyses, inhibits the timely analysis of data, and severely limits the development of predictive capabilities. The objective is an integrated system that allows users to seamlessly exploit multiple data sets from a variety of disparate programs. The linkage between data and products should be internal to the observing system and transparent to the users of data products.

II. Synopsis of the Coastal Component of AToward a U.S. Plan for an Integrated, Sustained Ocean Observing System@ (http://core.cast.msstate.edu/NOPPobsplan.html)

A. Background

There are many U.S. observing systems and monitoring programs in place that serve the needs of a large and varied user community. These systems provide data that helps mitigate loss of life and property, enhances private enterprise, ensures national security, provide information to mitigate anthropogenic changes to the environment, as well as other positive benefits. However, these efforts are not integrated; they do not constitute a complete system; they are not responsive to the needs of many users; and they are not as cost effective nor useful as they could be. Unlike weather information, however, a considerable fraction of the existing ocean observations is funded, managed, and utilized by many different groups, agencies, institutions, and individuals, for as many purposes. Thus, a key issue for a national ocean observing system is integration of disparate observational systems and data sets to maximize their utility for many users and purposes. By formulating and implementing a plan for an integrated national ocean observing system, the U.S. will better serve a wider array of users with only modest increases in costs relative to the additional benefits.

The requirements for data on physical and meteorological processes of coastal waters are similar to those of the open ocean (e.g., changes in sea surface temperature and salinity fields on daily to decadal scales; surface fluxes of heat, water and momentum; surface wind stress, waves and circulation patterns) with the important exception that the spatial and temporal resolution of measurements must be finer in coastal systems. **These commonalities provide the framework for building the fully integrated system (open ocean to inland sea)**.

In addition to physical and meteorological variables, the coastal component of the integrated ocean observing system (OOS) must incorporate measurements of the chemical and biological properties to quantify and predict natural and anthropogenic forcings and their consequences (Table 1 in the main text). This reality underscores important distinctions between open ocean and coastal aspects of the observing system. These include

- **$** the extent to which the ocean-climate system is operational relative to the coastal system which must, in the end, address a broader spectrum of socially relevant issues; and

- **$** differences in spatial and temporal scales of sampling required.

Thus, the initial plan calls for an open ocean subsystem and a subsystem for coastal waters with a common infrastructure for physical and meteorological observations. Here coastal waters include the U.S. EEZ, estuaries, bays, sounds, and the Great Lakes.

B. Coastal Ocean Recommendations

The purpose of the coastal component of the observing system is to provide a framework of measurements and analysis required to (i) quantify inputs of energy and materials from land, air, ocean, and human activities and to (ii) detect and predict the effects of these inputs on human populations living in the coastal zone, on coastal ecosystems and living marine resources, and on coastal marine operations. The goal is to design and implement an integrated observing system for coastal waters that will achieve this end by building upon existing networks and programs where appropriate. This approach is founded on the dynamics of aquatic ecosystem which suggest that there is a common set of core properties that, if measured with sufficient resolution in time and space, will serve many needs from forecasting wave heights in the coastal ocean and nowcasting water depth in major ports and harbors to managing nutrient inputs to coastal waters and fisheries management. As a first step in initiating a process that will lead to the design and stepwise implementation of the coastal component of the U.S. Integrated Ocean Observing System, the following general recommendations are made:

(1) Obtain more accurate estimates of inputs of freshwater, sediments, nutrients, and contaminants to coastal waters on local to regional and national scales through

- long-term, continuous measurements of flow volume at more sites; and

- more frequent sampling of key properties, including especially sediment load, nutrient concentration, and selected chemical contaminants.

(2) Improve marine meteorological forecasts and coastal circulation models; provide more timely detection of environmental trends; document the effects of human activities on coastal ecosystems; improve scientific information in support of fisheries management; and assess the efficacy of management actions through

- the development of an integrated *in situ* and remote sensing observing system for monitoring and predicting change in selected species of living resources and the quantity and quality of coastal habitats (intertidal, seagrasses, kelp beds, water column, and sediments);

- the development of an expanded and enhanced network of moored instruments in inland seas (estuaries, bays, sounds, the Great Lakes) and in the open waters of the EEZ for sustained, synoptic measurements of meteorological (including atmospheric deposition) and oceanographic (physical, chemical, and biological) properties deposition at more locations; and

- the development, evaluation and application of data assimilation techniques to physical and biogeochemical models.

(3) Identify and establish a network of coastal index sites (pilot projects) as a means to enable research to quantify the causes and consequences of environmental variability in coastal waters and improve predictions (nowcasts, forecasts) of environmental change and human impact in key locations.

(4) Implement a comprehensive and integrated program of *in situ* and remote measurements of water levels, surface waves and currents and timely dissemination of nowcasts and forecasts in all major ports and other coastal waters used for marine operations to improve the safety and efficiency of marine operations.

(5) Document changes in water depth (nearshore shallow water and the deeper waters of the EEZ) and shoreline topography through frequent high resolution topographic shoreline and nearshore bathymetric surveys, and less frequent high resolution bathymetric surveys of the continental shelf.

(6) Station locations and environmental variables to be measured will be determined through an objective assessment and numerical analyses that will consider the following:

- distribution of people in the coastal zone;

- the susceptibility of coastal environments to natural hazards; and

- sampling requirements for (i) producing routine and continuous estimates of coastal circulation, (ii) improving weather forecasts, predictions of natural hazards, and climatology and (iii) documenting changes in coastal waters caused by fishing, point and nonpoint discharges from coastal watersheds, and larger scale oceanic and climate variability.

(7) Establish a coastal data and information management system that leverages existing National Data Center capabilities and which can accommodate the anticipated high volume of data.

Given these considerations and the requirements of both documenting and predicting patterns of change, the observing system should consist of five key elements:

- **remote sensing** (from aircraft, satellites, and fixed platforms, e.g. high frequency radar) to capture the spatial and temporal dimensions of change in surface properties;

- ***in situ* measurements** to capture changes in time and depth (moored instruments, drifters, AUVs, ships);

- **index sites**, pilot projects and test beds will be needed to develop the models required to link observations to products in the form of predictions and early warnings, to demonstrate the efficacy of the GOOS approach, and to develop new technologies and approaches;

- **real time telemetry** and **data assimilation** for timely access to and applications of environmental data; and

- an **effective data management** system that accommodates the disparate coastal observation data systems/sources.

Appendix B

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72. Jim Yoder, University of Rhode Island

Appendix C

Abstracts of Background Papers

1. Glenn, S.M., W. Boicourt, T.D. Dickey and B. Parker. Long-Term, Real-Time Observation Networks for Ports, Estuaries and the Open Shelf.

ABSTRACT: Ocean observation networks for ports, estuaries and the open shelf are currently operating or are being constructed at numerous locations around the country. The rationale for their construction and maintenance include both long-term and real-time applications. Enabling technologies that make this possible now are the rapid advancements in sensor and platform technologies, multiple real-time communication systems for transmitting the data, and the emergence of a universal method for the distribution of results via the World Wide Web. Representative observation networks highlighted here include one for harbors (PORTS), a second for estuaries (CBOS), and a third for the open coast (LEO-15). Each network is described in terms of its system specific goals, its current capabilities, and its recent accomplishments. Future sensors and platforms that will expand the observation capabilities in all three regions are described. A common set of limitations each network must address includes operational support, instrument calibration, bio-fouling, power requirements, and data management. Future recommendations include the training of a new generation of computer and field support personnel. and the development of partnerships and long-term support mechanisms to foster the formation of a National distributed observation network.

2. Haidvogel, D.B., J. Blanton, J.C. Kindle, and D.R. Lynch. Coastal GOOS: Processes, Models and Real-Time Systems

ABSTRACT: The coastal oceans are among the most challenging marine environments in the world. Coastal circulation patterns include persistent and time-variable fronts, intense currents (jets), coastally trapped waves, internally generated mesoscale variability, strong vertical and horizontal gradients, and regions of intense turbulent mixing in both surface and bottom boundary layers. Numerical models, based on fully nolinear stratified primitive equations, are becoming increasingly complex. This review (i) provides a brief description of the physical environment and processes that dominate regional circulation patterns; (ii) discusses three coastal circulation models (the Princeton Ocean Model, the Regional Ocean Modeling System, and the Dartmouth Finite Element Model) which as a group represent the present state-of-the-art in coastal circulation modeling; and (iii) describes several ongoing, real-time and near-real-time applications of these numerical models in the Gulf of Mexico, the New York Bight, the Gulf of Maine, the California Current System and Alaskan Continental Shelves.

3. Walstad, L.J. and D.J. McGillicuddy. Data Assimilation for Coastal Observing Systems

ABSTRACT: Data assimilation is being applied to estimate the state of the coastal environment. Data assimilation is described as a procedure that produces an estimate of the past, current, or future state of the environment using measurements and a dynamical model. These procedures may be classified as filters and smoothers. Filters are characterized by the use of data to predict only the future state. Data does not affect the state estimate for times prior to the time of the measurement. Smoothers create estimates that exploit all available data to estimate the state of the system at a particular time. While optimal estimates such as the Kalman filter are known, approximations to these algorithms are commonly used. Smoothers are generally computationally expensive and have been used only for small or simple systems.

The meteorological community has significantly more experience using data assimilation, than does the oceanographic community. Commonly applied atmospheric algorithms use filters as do most existing oceanographic applications. Examples include the Chesapeake Bay LAPS system, the Chesapeake Bay Regional Analysis and Modeling System, and the Chesapeake Bay Estuarine Forecast System. These systems are producing useful estimates of the physical environment now and are expected to improve in resolution and reliability. Another lesson is the utility of reanalysis, the application of an assimilation system to an extensive historical data set. As we develop databases and assimilation capabilities, we should plan for reanalysis activities.

Of particular interest at this time, as we plan the observational resources to be placed in the coastal ocean, is the observing system simulation experiment. These may be used to evaluate the errors associated with a particular sampling system. Similarly, identical time experiments can be used to identify the strengths and weakness of assimilation procedures.

Finally, while assimilation of biological and chemical data has not been extensively applied. The GLOBEC Georges bank study has used these techniques to estimate both the distribution of zooplankton and also the sources and sinks of this organism. Because the physical transport models have become mature, reliable tools, biological and chemical data assimilation is expected to come into widespread use in the next few years.

4. Fox-Norse, V., R. Bailey, W. Boynton, A. Frankic, and J. Proni. Driving Science and Management Issues and Related Information Needs

ABSTRACT: Coastal management issues may be classified into three categories: (i) ecosystem-habitat (e.g., invasive species, harmful algal blooms, water quality, habitat loss and modification, exploitation of living resources, aquaculture, alteration of freshwater flows, natural - perturbations and anthropogenic stressors); (ii) human health (direct and indirect effects of natural hazards, harmful algal blooms, toxic contamination, and pathogens); and (iii) socio-economic (municipal waste water treatment, availability of potable water, international trade, urban growth, fisheries, demographic patterns). C-GOOS should focus on coastal areas with large and increasing populations, extensive infrastructure, and valuable natural resources. The system should be sufficiently flexible to accommodate new environmental issues, the timing, nature, and extent of which are as yet unknown. The coastal observing system should (i) provide data products that are relevant on local, regional and national scales; (ii) incorporate long-term, high resolution time series measurements to capture episodic events and low frequency variability; (iii) emphasize real-time data telemetry; (iv) serve to coordinate research and monitoring regionally and nationally; and (v) facilitate the integration of data from disparate sources collected on different time and space scales, e.g., remote and *in situ* sensing. Partnerships between federal, state and

local entities will be required to insure coordination and capacity building at the local and state level.

Related science issues include (i) quantification of water and material inputs; (ii) characterization of receiving waters in terms of water masses, circulation, habitats and associated biological and chemical features; (iii) characterization of cross-boundary exchanges; (iv) development and application of models to help in both exposure evaluations and analysis of transport and fate; (v) specifications for standards of precision and accuracy of measurements and scales of resolution; and (vi) means to establish standardized spatial scales for shoreline segments, maps, and charts for single estuaries and broader coastal segments, and for national use for informational databases and geographic information system applications.

5. Weisberg, S.B., T.L. Hayward, and M. Cole. Towards a U.S. GOOS: A Synthesis of Lessons Learned form Previous Coastal Monitoring Efforts.

ABSTRACT: The Global Ocean Observing System (GOOS) is an international initiative to collect, distribute, and exchange oceanographic data on a routine, long-term, systematic basis. Many of the programs that will be merged into GOOS, as well as other federal efforts with complementary long-term assessment missions, have previously undergone peer review and the lessons learned from these program reviews can provide instructive points for future GOOS planning efforts. Seven key themes were extracted from these reviews, as well as from our own insights about these programs, and are offered as a stimulus for discussion in planning for GOOS: 1) Clearly define program goals and anticipated management products, 2) Recognize the differing complexities between physical and biological monitoring systems, 3) Structural differences among ecosystems and among space-time scales affect sampling design, 4) Develop an effective data dissemination strategy, 5) Develop data products that will be useful to managers and decision makers, 6) Provide for periodic program review and flexibility in program design, and 7) Establish a stable funding base and management infrastructure.

Appendix D

Working Group Reports: Day 1, Designing an Integrated Observing System

Using the Coastal GOOS design process, design an integrated observing system that (1) meets the needs of multiple users and (2) is operational for the prescribed Ageneric@ coastal ecosystem. Assess current capabilities and deficiencies of existing observing systems in this context. Each working group was constituted to include representatives of each link in an end-to-end, user driven observing systems, i.e., users (in this case, managers and decision makers responsible for coastal environments and living marine resources), modelers of coastal systems, and scientists engaged in coastal observations. Each group was asked to emphasize a different set of forcings: shipping activities for ports, inputs from land for watershed-estuary-plume ecosystems, exploitation of living marine resources for western boundary coastal ecosystems, and large scale changes in climate and ocean circulation for eastern boundary coastal ecosystems.

A. Ports: **Larry Atkinson** (chair), Vernon Asper, Bob Bailey, Reginal Beach, Mark Bushnell, Muriel Cole, Dan Davis, Virginia Fox-North, Hank Frey, Grant Gross, Fred Klein, Mike Mickelson, Bruce Parker, John Proni, Ben Sherman.

1. Issues and User Groups

As illustrated by the table below, an integrated observing system for ports (defined as a geographic region that includes a port or harbor) may address a broad spectrum of issues and the needs of multiple user groups. Issues discussed by the group include safe and efficient shipping (cargo, navigation), hazardous materials (HazMat spill prevention and mitigation), dredging and disposal of dredge spoils, introduction and/or growth of nonindigenous species (exotic) and harmful algal blooms (HAB prevention and mitigation), loss of living marine resources (LMR) and habitats, and point source inputs of contaminants. Users can be divided into two groups, those that need access to real-time data streams and analysis (R) and those that require data and information collected over time and analyzed for a particular purpose (D). Some user groups have requirement in both categories. The shipping industry category includes shipping companies, ship masters, shipyards and cargo facilities. Port Authorities are also interpreted broadly to include pilots, port superintendents, port captains and harbor safety committees. Exporters and importers include oil companies. Most real-time needs (e.g., nowcasts and forecasts) are for safe and efficient shipping, hazardous material spills, and fishing and recreation.

Issues							
User Group	Cargo Limits	Navigation	Haz Mat	Dredging	HABs and Exotics	LMRs and Habitat	Contaminants
Shipping Industry	R/D	R		D	D		
Port Authorities	R/D	R	R	R			

Issues							
Exporters and Importers	R/D	R	R/D	D			
Coast Guard	R	R	R	R			
Law Enforcement	R	R	R				
ACE, MMS	D	D		D		D	
Public Health			R	D	R/D	D	R/D
HazMat Response			R				R
Insurance	D	D	D			D	D
Econ Dev Boards	D	D	D		D	D	D
LMR, Environ, CZ Managers			D	D	R	R/D	D
Regulatory Agencies			D	D	R	R/D	R
Local Government			R	D	D	D	D
Sanitation Districts						D	R/D
NGOs			D	D	D	D	D
Tourist Industry Recreating Public			R		R	D	D
Fishing industry		R	R	D	R	R/D	R
Military	R	R		D		D	
Scientists							

2. Form of Final Predictions and Lead Times

a. Real-time

$ water level (depth)

$ winds, currents, waves

$ temperature-salinity stratification

b. Predictions

$ water level 12-24 hours in advance

$ storm surge 48-72 hours in advance

$ oil spill trajectory 0-24 hours in advance

$ marine mammal paths/sitings (e.g., right whales) 0-24 hours in advance

c. Alerts

$ evacuation 24-72 hours in advance

[Note: Although this analysis does not address the question, i.e., what are acceptable lag times between measurement and the availability of the product(s), it does underscore the importance of considering both the lag time between measurement and product availability and the amount of lead time required for a prediction to be useful.]

3. Identification of the Types of Models to be Used and Model Inputs

Depending on the issue, lead time and status of model development, models will include coupled numerical models of ocean-atmosphere dynamics, statistical models, conceptual models (e.g., nonindigenous species), natural damage assessment models, physical models, and rish models that operate on small time-space scales.

Data on water level is currently monitored by NOAA-NOS at approximately 200 locations. NOS has also established PORT (Physical Oceanographic Real-Time) Systems at the harbor entrances of 3 major U.S. ports: New York-New Jersey, Tampa Bay, and San Francisco Bay. PORTS is in the process of being installed in Narragansett Bay, Houston-Galveston Bay, and the Soo Locks (Great Lakes). These systems consist of acoustic Doppler current profilers with anemometers, packet radio transmission equipment, data acquisitions system and an information dissemination system. Real-time data transmission helps vessel operators and maters, pilots, mariners, facility managers, etc. make sound decisions concerning tonnage limits for cargo, ETAs and ETDs, transit times, and a variety of related needs for safe and efficient navigation. NOAA plans to install PORTS to an additional 37 locations over the next 5 years.

PORTS has the potential of serving as building block for an integrated ocean observing systems. The working groups recommends that consideration be given to the design and implementation of an enhanced PORTS that integrates biological and chemical sensors into the overall package. This would expand the spectrum of user groups to include resource, environmental and coastal zone managers and planners, HazMat response teams, the fishing industry, natural disaster forecasters, etc.

4. ACost-Benefit@ Analysis (Impact-Feasibility Matrix)

Feasibility	Low Impact	Medium Impact	High Impact
Doable ($)	citizen data	barometric pressure surface temperature	water level nearshore winds
Difficult ($$)		temperature and conductivity (density) suspended sediments visibility (air)	offshore winds currents waves storm surge
Very Difficult ($$$)			exotic species in ballast water marine accident data base current structure

B. Watershed-Estuary-Plume Ecosystems: **Antonio Baptista** (chair), Bill Boicourt, Walter Boynton, Peg Brady, Larry Harding, Bill Fisher, Holly Greening, Michael Korso, Robert Magnien, Jonathan Phinney, Gary Powell, Chris Scholin, Dwight Trueblood, Sandra Vargo, Steve Weisberg, Catherine Woody

Communication (information flow) is essential, and the internet is a prime vehicle. Inter-connectivity of Asites@ is useful as a Alessons learned@ tool for users. Reliability and credibility of relevant information is what matters most to users. Modeling should, among other things, lead to a reduction of the observations needed over time. Effective use implies a progressive Aculture change@ that should be enabled by outreach and education at all levels from K-12 and undergraduate studies to graduate studies and lifelong learning.

1. Issues and User Groups

Issues to be addressed can be categorized in terms of inputs and responses. Inputs of concern are surface and groundwater flows from land, atmospheric deposition, oceanic exchanges and associated transports of nutrients, sediments, contaminants, and organisms. Responses should be analyzed in terms of assimilation capacity (including TMDLs); transport, sources and sinks within the system; causal interactions among ecosystem components; and indicators of response or change that include oxygen depletion, algal blooms, successful growth and development of nonindigenous and harmful species, mass mortalities, bacterial contamination (beach closures), decrease water clarity, and public health threats.

User groups include those responsible for changes in inputs (e.g., freshwater diversions, point and diffuse inputs of nitrogen and phosphorus); state and federal agencies responsible for managing or regulating inputs; and scientists responsible for understanding and predicting the effects of inputs, i.e., stakeholders responsible for or impacted by the TMDL (Total Maximum Daily Load) process and other management and regulatory actions, resource managers, policy making organizations (e.g., zoning boards, fisheries commissions), elected officials and their staff, groups responsible for outreach and education; the public; and the scientific community.

2. Form of Final Predictions/ Products and Lead Times

New products that change the way we do things will require sustained observing systems that will allow timely alerts, daily-seasonal forecasts, trend analysis and long-term prediction, the identification and measurement of indicators that are socially and economically relevant, and visualizations of change. Acceptable lag times between measurements and prediction range from zero in the extreme to decadal depending on the issue.

3. Identification of the Types of Models to be Used and Model Inputs

Models will be needed for a variety of purposes from defining and testing hypotheses to forecasting and prediction. They will be multi-level in their sophistication; capable of utilizing or assimilating data from disparate sources, collected on different time and space scales using methods of varying precision and accuracy; and interdisciplinary.

4. ACost-Benefit@ Analysis (Impact-Feasibility Matrix)

Feasibility	Low Impact	Medium Impact	High Impact
Doable		**acoustic backscatter**	**bathymetry water level temperature coastline erosion**
Difficult			**currents salinity nutrients chlorophyll bacteria and viral pathogens**
Very Difficult		**sedimentation-resuspension**	**turbidity dissolved oxygen trace metals organics harmful algal species**

C. Western Boundary Shelf System: **Len Peitrafesa** (chair), Earle Buckley, Cynthia Decker, Bruce Estrella, Scott Glenn, Fred Grassle, Richard Jahnke, Ken Johnson, Mark Luther, Tony MacDonald, Greg McMurray, Chris Mooers, Ken Tenore, Jim Yoder

1. Issues and User Groups

Issues include fluctuations in living resources, essential habitat and management in an ecosystem context (multi-species and adaptive management). User groups include commercial and recreational fisheries, managers of living marine resources (NMFS, State agencies, USCG, regional marine fishery councils), public health agencies, seafood (packing and distribution) industry, financial institutions, and scientists.

2. Form of Final Predictions and Lead Times

Final predictions depend on more comprehensive and effective stock assessments on daily to seasonal time scales and on improving our understanding of the relationships between fluctuations in stock abundance and biomass and the status of coastal ecosystems. Lead time for predictions varies depending on user needs. Managers of living marine resources require data and information on time scales that range from near real time for HazMat spills and fish kills to weeks-months for analysis of reproductive success and months-years for analysis of recruitment success. Fisherman require real-time to daily updates of weather, fronts, and temperature distributions. Public health officials require real time data for immediate response and data on longer time scales for analysis.

For the purposes of fisheries management, the penultimate model outputs are fish biomass and abundance for each species, year class, and stock unit on seasonal to annual time scales. Estimates of the effects of fishing, by-catch, and habitat modification and loss are needed. An example of a needed intermediate model output is the time-dependent dispersal of fish eggs and larvae in 3-D viewed in the context of Lagrangian drifter observations.

3. Identification of the Types of Models to be Used and Model Inputs

A system of connected (coupled) biophysical models are required to provide guidance to environmental and resource managers dealing with multi-species, whole ecosystem fisheries management. Typically, these are process-based, numerical models that are guided by observations. The modeling systems will build on 3-D, time dependent, coupled atmospheric-ocean models that calculate current, temperature and salinity fields. A typical coastal circulation model will have a horizontal resolution of 1 km, vertical resolution of meters, and a temporal resolution of 1 hour. Circulation models will be used to drive dispersal models for fish eggs and larvae, oil spills and search and rescue operations. They will also be used to drive, individual-based, multi-species ecosystem models. Biological models that will be coupled to physical models include recruitment, bioenergetic, and population dynamic models.

Models of population dynamics and bioenergetics and stock assessments (pelagic, demersal, crustaceans, bivalves) are essential. Additional input data are required on winds, waves, currents, temperature, salinity, fronts, nutrients, phytoplankton biomass and floristic composition, macro-zooplankton, bathymetry, essential fish habitat, harmful algal blooms, and fish kills.

The requirements of models for input data depend on the accuracy required for a particular application. In addition to stock assessment data, it is clear that information on physical-biological interactions is needed for all trophic levels. Adaptive sampling and Lagrangian measurements will need to be build into the observing system design. Procedures exist for determining the benefits of assimilating observations from candidate observing systems, e.g., Aantenna design@, observing system simulation experiments (OSSEs), and sampling experiments. This essential applied research has yet to be done for physical or ecological dynamics in the coastal ocean.

4. ACost-Benefit@ Analysis (Impact-Feasibility Matrix)

Feasibility	Low Impact	Medium Impact	High Impact
Doable		**tides** **waves**	**winds** **precipitation** **river runoff** **currents** **sea level** **temperature**
Difficult		**ice cover** **nutrients**	**salinity** **dissolved oxygen** **turbidity** **spectral attenuation**
Very Difficult		**turbulence** **zooplankton species** **benthos** **fish eggs and larvae** **top predators**	**phytoplankton species** **juvenile fish species**

D. Eastern Boundary Coastal Ecosystems: **Wendell Brown** (Chair), Neil Andersen, Ralph Cantral, John Cullen, Curt Davis, Tommy Dickey, Anamarija Frankic, Andrew Garcia, Robert Grumbine, Dale Haidvogel, Tom Hayward, Dale Keifer, Marlon Lewis, Dale Pillsbury, Oscar Schofield, Chris von Alt, Leonard Walstad

1. Issues and User Groups

The problem of emphasis is local manifestations of large scale forcings (e.g., El Nino, global warming, storms, atmospheric deposition, large scale fish harvesting) including the susceptibility to natural hazards, habitat modification and loss, and fluctuations in living resources. Issues of concern to environmental managers were identified as follows: evacuation, search and rescue, oil spills, contaminated sediment resuspension, beach closures (due to waves, erosion, contaminated runoff), watershed responses (flooding, sediment loading, groundwater contamination), atmospheric deposition of pollutants, public health, ecosystem health, degradation of habitat, and declines in fish stocks. The objectives of a coastal observing system for large-scale forcing are to

C describe large-scale, long-term trends (as the basis for anomaly assessment);

- provide data and information relevant to the framework of ecological and physical Acorrelates@

- used by managers for decision making; and

- provide an interdisciplinary suite of predictions.

2. Form of Final Predictions and Lead Times

Forcing	Form of Prediction	Lead Time
El Nino	Alert	6 months
	Classification index of strength, e.g., temperature and productivity anomalies	Months - weeks
	Animated visualization, e.g., SST and associated changes in species distributions	Months - weeks
Storm Events	Storm surge, flooding, habitat loss	Hours - days
	Off-shore environment (wind vectors, sea state, currents, SST)	

3. Identification of the Types of Models to be Used and Model Inputs

Four general types of modeling are considered necessary for resolving critical environmental factors over relevant scales.

- Fine-scale meteorological models are critical for forcing ocean models and should provide a suite of data products, e.g., local wind fields for mariners.

- Nested circulation models (with data assimilation) from basin scale to mesoscale shelf (to ~ 300 miles offshore) and inner shelf-nearshore models (0-30 m) will be needed to predict flow fields and provide the physical component for coupled physical-ecological models.

- Bottom boundary models will be needed to predict sediment resuspension and transport relevant to shoreline erosion, the transport of contaminants, and the release of nutrients to the water column.

- Ecological models (empirical, theoretical, heuristic, predictive) will be needed to assess the effects of large scale forcings on water quality and living marine resources.

The observing system required to develop, calibrate and validate models and to fuel assimilation models should include the following building blocks:

- An expanded NDBC meteorological buoy network that is enhanced over time with additional sensors for physical, biological and chemical oceanographic processes and properties;

- Develop a coastal network of high frequency radar stations (e.g., CODAR) for real-time measurements of surface currents for assimilation modeling;

- Remote sensing for SST, altimetry and ocean color;

- Ships and AUVs to maintain *in situ* sensing network, define important physical features, and provide routine measurements of critical biological and chemical properties (e.g., expand and enhance CalCOFI).

The group agreed on five priorities. (1) Run OSSE's to define observational needs (e.g., determine the required grid resolution of *in situ* sensors for physical models or of *in situ* optical data required to extrapolate satellite ocean color imagery to the vertical); (2) Develop mesoscale models of couple physical-ecological processes that are responsive to the needs of coastal managers; (3) build offshore array of platforms by augmenting existing platforms and expanding them to address specific problems with guidance form OSSE analysis; (4) develop a long-term funding base to insure continuity; and (5) develop training programs to augment and enhance existing personnel needed to implement, operate and maintain the expanded system.

Appendix E

Working Group Reports: Day 2, The Elements of An Integrated Observing System

Having engaged in the exercise of thinking through the design of observing systems from the perspective of a user group (environmental and resource managers), working sessions on day 2 focused on issues and needs of each level in an integrated observing system and the groups were more homogeneous.

A. Environmental and Resource Management in the Coastal Zone: **Gary Powell** (Chair), Bob Bailey, Peg Brady, Ralph Cantral, Bruce Estella, Bill Fisher, Virginia Fox-North, Anamarija Frankic, Holly Greening, Fred Klein, Tony MacDonald, Greg McMurray, Mike Mickelson, Dwight Trueblood, Steve Weisberg

Three questions are to be addressed by the group: (1) What are the key resource management issues that need to be addressed? (2) What information is needed to make effective management decisions? (3) How can C-GOOS add value? The group identified three general issues that are relevant to an integrated coastal observing system: (1) human health and safety, (2) ecosystem integrity, and (3) sustainable economy.

From the management perspective, an integrated, coastal observing system must be a reliable and credible source of data and information; it must be accessible by issue and by geographic location; it must incorporate relational, distributed data bases (e.g., for GIS); and it must be relevant to several different user groups. To meet these criteria, C-GOOS must provide a regional perspective for understanding and predicting local conditions; it must be supported by local-regional partnerships; and it be organized in terms of large scale marine ecosystems.

In terms of information needs, highest priority should be placed on the quantification of material fluxes to coastal ecosystems (e.g., erosion, nutrient enrichment, chemical contamination), resolving natural and anthropogenic sources of variability, circulation within and between ecosystems of the coastal ocean (from estuaries and bays to the open waters of the EEZ), and the effects of land-use practices. Emphasis should be placed on status and trends and the development of reliable early warning systems. The establishment of coastal index sites that address issues of ecosystem integrity is a very high priority in this regard. These should include the National Estuarine Research Reserves, National Estuary Programs, National Marine Sanctuaries, Coastal Index Site Networks, and Coastal LTERs.

B. R&D for *in situ* sensing: **Richard Jahnke** (Chair), Vernon Asper, Wendell Brown, Dan Davis, Tommy Dickey, Andrew Garcia, Fred Grassle, Rick Greene, Ken Johnson, Michael Korso, Dale Pillsbury, John Proni, Oscar Schofield, Chris Scholin, Sandra Vargo, Chris von Alt, Catherine Woody.

The group was asked to address the following question: What is the potential of *in situ* sensing as a component of coastal observing systems and how can it be realized? What are the R&D priorities for *in situ* sensing? What is operational; what is not; and what must be done to achieve operational status in response to the needs of multiple user groups (e.g., scientists, state and federal agencies, industry, NGOs)? The current status of *in situ* sensors is summarized below (Op - operational; Av - available but not routine; Res - sensors for research; Dev - under development and desirable for observing system). Note that the need for sensor research and development increases from physical oceanography to chemical and biological oceanography.

Discipline	Variable	Op	Av	Res	Dev
Meteorology	Wind, Temperature,	x			
	Barometric pressure	x			
	Full met sensors			x	
Physical Oceanography	Temperature, Conductivity	x			
	Sea level, Currents, Waves	x			
	Solar radiation	x			
	Optical properties			x	
Chemical Oceanography	Dissolved oxygen		x		
	Dissolved inorganic nutrients		x		
	Turbidity		x		
	Dissolved organic matter			x	
	Trace metals			x	
	Specific compounds				x
Biological Oceanography	Chlorophyll		x		
	Bacteria and pathogens				x
	Phytoplankton species				x
	Harmful Aalgal@ species				x
	Fish abundance and identification				x
Multidisciplinary	Controlled samplers		x		
	Video			x	
	In situ mass spectrometers				x

Priority areas for research and develop are sensors for harmful algal species, bacteria, dissolved oxygen, fish stock assessment, and the dispersal and dilution of point source inputs. Biofouling is a major problem for biological, chemical and optical sensors. Emphasis should be placed on bi-directional communications with sensors (data transmission and control of sampling rates) and platforms that provide for Aplug-n-play@ capabilities. Standardization, calibration and certification are major issues in the transition from research to operational modes. Clearly, meaningful advances in R&D will require stable funding for engineering groups.

Among other things, this analysis underscores the reality that the development of an integrated, interdisciplinary observing system should be an evolving process that incorporates chemical and biological sensors as they become available. Given the importance of the physical setting to the understanding of ecosystem dynamics and the status of sensor development, the initial set of core measurements will by necessity focus on the physics of coastal systems. The design of a fully integrated system should include a tiered system of measurement packages and must consider attributes that are regionally unique. The system will employ a mix of platforms from moorings (buoys and bottom mounted, fixed and profiling), drifters, AUVs, ROVs and ships depending on regional needs. Finally, networks of *in situ* sensors will become increasingly important as a source of data to calibrate and validate remote sensors.

C. Research and Development for Remote Sensing and for Integrating *In Situ* and Remote Sensing: **Scott Glenn** (Chair), Larry Atkinson, Reginald Beach, Jack Blanton, Walter Boynton, Curt Davis, Larry Harding, Tom Hayward, Dale Keifer, Mark Luther, Chris Mooers, Len Pietrafesa, Jim Yoder

The group addressed four related questions: (1) What is the potential of remote sensing as a component of coastal observing systems and how can it be realized, (2) what are the R&D priorities for remote sensing, (3) how will integrated remote and *in situ* sensing lead to better nowcasts, forecasts and predictions and (4) how can this potential be realized? It should be emphasized that none of the satellite systems currently in use were designed to examine coastal processes *per se*.

1. Potential

Remote sensing provides synoptic, 2-D fields and real-time observations at low (1 km), medium (0.3 km) and high resolution (0.03 km) spatial resolution. Remote sensing from satellites, aircraft and land based systems also provide the means to obtain long-term time-series measurements and data for visualization and animation of processes, capabilities that are required to capture and predict scale-dependent patterns of variability. Remote sensing from aircraft is capable of resolving sea surface temperature, salinity, and ocean color on scales of ~ 10 m. Photography also provides important data on erosion and habitat changes. Shore-based sensors for surface waves (LIDAR) and currents (high frequency radars) will also become important components of an integrated observing system. The status of satellite based remote sensing that is relevant to coastal waters is summarized below.

Status	> 1 km	Resolution >0.3 km	< 0.3 km
Operational	AVHRR (SST, sea ice) SAR (sea ice)	SAR (sea ice)	SAR (sea ice)
Research-Operational	Altimeter (currents) Scatterometer (winds) SeaWiFS (ocean color) VISSR (SST, surface plumes)		MERIS, GLI (ocean color, sea ice)
Research	(?) (salinity)	SEI (multi-purpose imagery for tidal fronts, red tides, coastal disasters)	NEMO (bottom characteristics, coral reef health, ocean color)

2. R&D Priorities

The top priorities for remote sensing are as follows:

- sustained calibration and validation of sensors including local algorithms for ocean color (chlorophyll, floristic groups, harmful algal blooms), suspended sediments, light attenuation, and other water quality attributes;

- responsive (targetable, pointable) platforms including satellites, autonomous aircraft (e.g., Special Events Imager as a new satellite concept for GOES);

- better estimates of water inputs from land and exports to the coastal ocean; and
- regional demonstration projects to explore optimum mixtures of remote and *in situ* sensing and assimilation modeling to generate products relevant to user needs

Additional priorities include more timely interpretation and dissemination of data products (e.g., World Weather Watch), development of operational sensors for monitoring coastal aerosols, use of aircrafts of opportunity (especially in regions with persistent cloud cover, e.g., Coast Guard aircraft), development of sensors to measure winds at higher resolution (1 km) in coastal waters, altimetry in coastal waters, extend HF offshore and inshore, improve aircraft and satellite salinity mappers, improve capabilities to monitor bottom characteristics and habitats (including coral reef bleaching), and acoustic remote sensing for 3-D mapping of temperature, currents, bottom topography and large particle characteristics.

3. Integrated Remote and *In Situ* Sensing

The scarcity of observations on coastal ecosystems of sufficient duration, spatial extent, and resolution and the lack of real-time data telemetry, assimilation and visualization are major impediments to the development of a predictive understanding of environmental variability in coastal waters. Remote sensing provides spatially synoptic Asnap shots@ of surface properties. The strength of *in situ* sensing is in its capacity to provide high resolution time series measurements and to measure physical, chemical and biological variables simultaneously. Both are able to communicate data in real-time. In addition to validation and calibration (discussed by the working group on *in situ* sensing above), the integration of data from remote and *in situ* sensors will lead to improved nowcasts and predictions by providing

C the means to visualize 3-dimensional, time-dependent changes,

C data and information required to guide adaptive sampling for more accurate interpolation in space (horizontally and vertically), and

C real-time data for improved prediction.

4. Achieving the Potential

In addition to sensor development, a system of data management is required that (1) captures data from different sources, collected on different time and space scales and measured by different methods; (2) establishes the quality of the data; (3) rapidly disseminates data; (4) synthesizes and interprets data in a more timely fashion; and (5) generates products that are responsive to user needs. To achieve this, pilot projects are needed that demonstrate the utility and cost-effectiveness of end-to-end, integrated observing systems on regional scales.

D. Research and Development for Nowcasting, Forecasting and Prediction: **Marlon Lewis** (Chair), Neil Andersen, Antonio Baptista, Bill Boicourt, Earle Buckley, Mark Bushnell, John Cullen, Muriel Cole, Hank Frey, Grant Gross, Robert Grumbine, Dale Haidvogel, Bruce Parker, Jonathan Phinney, Ben Sherman, Ken Tenore, Leonard Walstad

The group was asked to address the following questions: How can our capacity to assimilate and interpret large volumes of data be improved for research and applied purposes? What advances will be needed to improve assimilation modeling, the visualization of pattern, nowcasting, and prediction? How will advances in these areas affect our ability to detect and predict change in physical and ecological states?

As a starting point, a consensus was achieved on guiding principles. The value or benefit of an observation, or an observation system, is in its ability to significantly improve assessment and prediction in support of decision making. Models provide the links between data and useful information products and, to that end, the focus was on the research and development requirements to improve data assimilation with a view towards improved prediction skill in the coastal environment and on appropriate means to present and convey the resulting information.

1. Priorities for fine-scale coastal meteorological analyses and forecasts

a. Models

- Improve resolution to 2-4 km for inshore environments and

- Develop nested models at different scales (from high resolution, local models inshore to lower resolution, large scale models offshore).

b. Data requirements

The coastal ocean is severely undersampled, a situation that must be addressed if regional forecasting is to be improved and oceanic-atmospheric processes are to be linked in a predictive mode. The single most important measurement is sea surface wind. Additional priorities are barometric pressure, humidity, air temperature, SST, wave amplitude and directional spectra, and sea ice.

c. Priority implementation issues

First steps include (1) increasing the number of fixed and drifting platforms, wave riders and directional buoy arrays; (2) deploying improved scatterometry, altimetry, SAR and ocean color sensors for coastal waters; (3) implementing quality control measures; (4) improving error analysis of property fields; and (5) developing simple graphical and interactive means to generate useful products (need for additional layer of analysis beyond model outputs).

2. Analysis of coastal physical dynamics and prediction of circulation and mixing regimes

a. Models

$ Current resolution of barotropic, vertically integrated models is adequate (10 km), but baroclinic models with vertically resolved properties should achieve a resolution of < 3 km and

$ Continued development of nested models (as for atmospheric models above).

Priority research and development issues that must be addressed include (1) parameterization of unresolved physical processes involving improved horizontal resolution of depth (50 m) and bottom stress; (2) improvements in assimilation modeling (e.g., variational methods, variability in three dimensions, successive corrections); (3) development of more effective approaches of dealing with the sparsity of data and specification of covariance field error; (4) model validation; and (5) improvements in both the ability of models to handle sharp discontinuities and to estimate Lagrangian transport.

b. Data requirements

Observing system simulation experiments (OSSEs) are needed to evaluate the impact of resolution (time, space, system components) on model predictions (Askill@). Data requirements (observations) for model validation should be established, and model intercomparisons should be rigorous and common place.

c. Priority implementation issues

Monitoring, model outputs, and products must be tuned to user needs. Product development should be commercialized.

3. Analysis and prediction of ecologically and socially important processes

a. Models

Current models are immature and predicting ecological variability and change should be a high priority. In this regard, greater emphasis should be placed on the development of assimilation models that predict changes in ecosystem dynamics (biogeochemical processes, trophic dynamics) and their consequences. Initial focus should be on the formulation of simple models with realistic physics, e.g. passive transport of harmful algae, highly parameterized, non-conservation behavior such as growth, sinking and feeding.

b. Data requirements

Model experimentation (e.g., OSSEs) is required to identify priority properties and scales of variability. Initially, power of properties such as ocean color, light attenuation, acoustic backscatter, and dissolve oxygen should be tested.

c. Priority implementation issues

Models should be available for wide use to evaluate trends using archived data of ecologically important variables. The development and testing of models for short-term Langrangian transport problems are a high priority as are highly parameterized models with validation. Metadata requirements should be defined and simple procedures established for insuring that metadata requirement are met. Model outputs must be transformed into useful products (Aanalyst layer@).

Appendix F

Acronyms

AVHRR	Advanced Very High Resolution Radiometer
CalCOFI	California Cooperative Fishery Investigation
CEOS	Committee on Earth Observation Satellites
CISNet	Coastal Index Site Network
C-GOOS	Coastal-Global Ocean Observing System
C-MAN	Coastal Marine Automated Network
COE	Corps of Engineers
CoOP	Coastal Ocean Processes Program
COP	Coastal Ocean Program
EEZ	Exclusive Economic Zone
GCOS	Global Climate Observing System
GLI	Global Imager
GLOBEC	Global Oceans Ecosystem Dynamics Program
GODAE	Global Ocean Data Assimilation Experiment
GOES	Geosynchronous Operational Environmental Satellite
GOOS	Global Ocean Observing System
GTOS	Global Terrestrial Observing System
ICSU	International Council of Scientific Unions
IGBP	International Geosphere-Biosphere Program
IOC	Intergovernmental Oceanographic Commission
JGOFS	Joint Global Ocean Flux Study
LEO	Long-term Ecosystem Observatories
LMER	Land-Margin Ecosystem Research Program
LOICZ	Land-Ocean Interactions in the Coastal Zone
LTER	Long-Term Ecological Research
MERIS	Medium Resolution Imaging Spectrometer
NAML	National Association of Marine Laboratories
NAWQA	National Water Quality Assessment Program
NERRS	National Estuarine Research Reserve System
NODC	National Oceanographic Data Center
NOPP	National Oceanographic Partnership Program
NORLC	National Ocean Leadership Council
NOS	National Ocean Service
ORAP	Ocean Research Advisory Panel
PORTS	Physical Oceanographic Real-Time System
SAR	Synthetic Aperture Radar
SEI	Special Events Imager
UNCED	United Nations Conference on Environment and Development
VISSR	Visible and Infrared Spin-Scan Radiometer
WMO	World Meteorological Organization